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<p>(21) International Application Number: <b>PCT/SE97/01678</b></p> <p>(22) International Filing Date: <b>8 October 1997 (08.10.97)</b></p> <p>(30) Priority Data:  <b>9603798-1</b>      <b>16 October 1996 (16.10.96)</b>      <b>SE</b></p> <p>(71) Applicant (for all designated States except US): <b>ABB RESEARCH LTD. [CH/CH]; c/o Asea Brown Boveri AB, Patent, S-721 78 Västerås (SE).</b></p> <p>(72) Inventors; and  (75) Inventors/Applicants (for US only): <b>JOHANSSON, Kenneth [SE/SE]; Bangatan 23 B, S-722 28 Västerås (SE). KOLS, Håkan [SE/SE]; Klockartorpsgatan 31 E, S-723 44 Västerås (SE).</b></p> <p>(74) Agent: <b>LUNDBLAD VANNESJÖ, Katarina; Asea Brown Boveri AB, Patent, S-721 78 Västerås (SE).</b></p>	<p>(81) Designated States: <b>AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</b></p> <p><b>Published</b>  <i>With international search report.</i>  <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>  <i>In English translation (filed in Swedish).</i></p>	
<p>(54) Title: <b>A DEVICE FOR MONITORING PARTIAL DISCHARGES IN AN ELECTRIC HIGH-VOLTAGE APPARATUS OR HIGH-VOLTAGE EQUIPMENT</b></p>		
<p>(57) Abstract</p> <p>A device for monitoring partial discharges in high-voltage equipment (1), which has a high-voltage bushing (21, 22, 24) with a capacitive test tap (31, 33, 34). The device has an inductive current transducer in the form of a measuring coil (4) arranged around the high-voltage bushing, as well as signal-processing members (SB) which, for detection of partial discharges, are supplied with measurement signals from the coil (u) and from the test tap (i). The device further comprises a current path (36) which is coupled to the test tap and arranged outside the coil and which, together with the conductor (24) of the bushing, forms a current loop around the coil for signals (i) coming from inside the apparatus and originating from partial discharges.</p>		

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A device for monitoring partial discharges in an electric  
high-voltage apparatus or high-voltage equipment

#### TECHNICAL FIELD

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The present invention relates to a device for monitoring partial discharges in such electric high-voltage equipment or high-voltage apparatus, for example a high-voltage transformer, which has a high-voltage bushing with a  
10 capacitive test tap. The device comprises an inductive current transducer in the form of a measuring coil arranged around the high-voltage bushing, and signal-processing members adapted, for detection of partial discharges, to be supplied with signals from the inductive  
15 current transducer and from the capacitive test tap.

#### BACKGROUND ART

From the older Swedish patent application 9501664-8, which  
20 corresponds to the international patent application PCT/SE96/00558, a device and a method for monitoring partial discharges in an electric power transformer are previously known. The transformer has a high-voltage bushing with a capacitive test tap, from which a  
25 measurement signal is obtained which is a measure of the electric field at the bushing. An inductive transducer in the form of a coil system, arranged around the bushing, delivers a measurement signal corresponding to the current through the bushing. The two measurement signals are  
30 supplied to signal-processing members. In these, the signals are multiplied by each other, which makes it possible to distinguish internal discharges from external disturbances or other signals. Further, the signal-processing members comprise means for closer analysis of  
35 the measurement signals, for example for determining the level of the internal partial discharge and for triggering an alarm signal if the level exceeds a predetermined alarm level.

It has proved that this known device has certain disadvantages. Thus, the sensitivity of the device to internal discharges varies with the working conditions of the transformer, and under certain circumstances the sensitivity is annoyingly low. Further, the sensitivity to internal discharges, that is, the discharges which are of interest, is always lower than the sensitivity to external discharges or other external disturbances, which is an obvious disadvantage. The difference in sensitivity to external and internal discharges also makes the calibration of the device difficult.

In the known device, the two measurement signals originate from transducers of different types - one capacitive test tap and one inductive measuring coil. Since the signals during the signal processing are multiplied by each other, they must have the same phase occurrence. To achieve this, the input circuits of the signal-processing members for the two measurement signals must be different, and further, individual adjustment of the input stages in dependence on, inter alia, cable length and type of bushing is required.

The galvanic connection from the capacitive test tap to the signal-processing members further entails a not insignificant risk of the latter being subjected to overvoltages or other disturbances, for example in case of lightning strokes or other disturbances on the network to which the transformer is connected.

In the known device, the current from the capacitive test tap must pass back and further through the cable and the contact means which couple the test tap with the signal-processing members, and in the latter through that impedance network in the form of resistors, capacitors and inductors which is included in the matching circuits of the input stages. This involves a not insignificant risk of interruption in the circuit, which in turn entails a risk of damage to the bushing.

## SUMMARY OF THE INVENTION

- It is an object of the invention to provide a device of the kind stated in the introduction, which, compared with prior art devices of the relevant kind, has increased sensitivity for detection of internal partial discharges and at the same time a reduced sensitivity to external partial discharges or other disturbances.
- 10 Another object of the invention is to provide a device in which, to make possible a simple and accurate calibration, the sensitivity can be made similar for both internal and external discharges.
- 15 A further object of the invention is to provide a device in which the input stages of the signal-processing members may be designed identical, and in which the need of individual adjustment is eliminated.
- 20 A still further object of the invention is to provide a device which offers greater operating and personal safety and exhibits less sensitivity to disturbance than the prior art device.
- 25 What characterizes a device according to the invention will become clear from the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

- 30 The invention will be explained in more detail in the following with reference to the accompanying Figures 1-5, wherein
- Figure 1 shows a prior art device of the kind described above, wherein Figure 1a schematically shows the construction of the device and its connection to a power transformer, wherein Figure 1b illustrates the function in case of an internal discharge, and wherein Figure 1c shows the function in case of an external discharge,

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Figure 2 shows the principle for a simple embodiment of a device according to the invention,

Figure 3 shows an embodiment of the invention with current-distributing members which distribute the current from the capacitive test tap between two current paths, one of which runs outside the measuring coil and one of which traverses the coil,

Figure 4 shows a variant of the embodiment shown in Figure 3, wherein the two terminals of the capacitive test tap are used for coupling of the measuring conductors from the test tap,

Figure 5 shows a preferred embodiment wherein the current-dividing member is constituted of a first current transformer, and wherein a second current transformer is adapted for measurement of the current from the capacitive test tap.

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#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1a shows a prior art device, known from the above-mentioned older patent application, for monitoring partial discharges in an electric power transformer. The figure schematically shows a transformer 1 with a bushing 2. The bushing has a metal pipe 21 which is attached to the casing of the transformer. The pipe 21 supports an insulator 22, in which the conductor 24 (see Fig. 1b) of the bushing is arranged and connected to the electrical connection 23 of the bushing. The bushing has a conventional capacitive test tap with a connection box 32. From the test tap (in case of a change of the voltage on the conductor of the bushing), a measurement signal is delivered in the form of a current "i". Around the lower part of the bushing, a measuring coil 4 is applied, and from this a measurement signal "u" is obtained (in case of a change of the current in the conductor of the bushing). The measurement signals are supplied to a signal-

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processing member SB via cables 35, 41 (e.g. coaxial cables).

Both the measuring coil 4 and the signal-processing member  
5 SB are suitably designed in the manner described in the  
above-mentioned patent application. Thus, the measuring  
coil is preferably a whole or divided Rogowski coil, and  
the signal-processing members are suitably adapted (after  
necessary matching, filtering, amplification, etc.) to  
10 multiply the two measurement signals, which makes possible  
a determination of whether a detected partial discharge  
originates from inside the transformer or is caused by an  
external discharge or other external disturbance. From the  
signal-processing member SB, a signal PDI is obtained  
15 which is a measure of the level or intensity of internal  
partial discharges in the transformer. In the manner  
described in the previous patent application, this signal  
may be supplied to a data-collection system for monitoring  
the transformer, for example for triggering an alarm if  
20 the discharge level exceeds a predetermined limit value,  
or for analysis of the condition and function of the  
transformer in dependence on the detected discharges.

Figure 1b schematically shows a section through the  
25 bushing in the device according to Figure 1a. The casing  
of the transformer 1 is shown connected to ground in the  
figure, and the potential of the transformer casing will  
hereinafter be designated "ground" although, in certain  
cases, the transformer may be erected on a potential  
30 deviating from ground. Via the conductor 24 of the  
bushing, the transformer is connected to a network,  
symbolically shown as an impedance element NI which  
corresponds to the impedance of the network, as viewed  
from the transformer.

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The bushing has a schematically shown capacitive test tap  
with two connection terminals 33 and 34. The terminal 33  
is coupled to a capacitor layer 31 arranged in the  
bushing, and the terminal 34 is coupled to the metal pipe

21, that is, to ground potential. The two terminals are coupled to the cable 35.

5 The measuring coil 4 is only shown schematically in the figure with its connection terminals 42 and 43, to which the cable 41 is coupled.

The measurement signals "i" and "u" are supplied to matching circuits ADP1 and ADP2 via the cables 35 and 41.  
10 The matching circuits are part of the input stage of the signal-processing member SB and comprise impedance networks with passive circuit elements in the form of resistors, capacitors and inductance elements for impedance matching of the inputs of the signal-processing member,  
15 and possibly also for matching of the levels of the signals to each other. The output signals of the matching circuits are forwarded to other circuits (not shown in the figure), included in the signal-processing member, for filtering, amplification, multiplication, etc.

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Figure 1b illustrates the function of the device in the case of an internal partial discharge. The discharge is assumed to be caused by a positive current out through the conductor 24. One part of the current, "i", is coupled to  
25 ground via the capacitive test tap, and another part, "iz", is coupled to ground via the network coupled to the transformer, for example via line capacitances, surge arresters and load objects. The total current caused by the discharge is thus  $i + i_z$ . However, the current "i" flows  
30 both back and forth through the measuring coil - up through the conductor 24 and down through the pipe 21 - and does not give rise to any net current through the coil. The only current which the coil measures is thus  $i_z$ . The measurement signal will therefore be dependent on the  
35 impedance of the load of the transformer. During high-voltage testing, for example, a load is not always connected, and the current sensed by the coil thus becomes low and the sensitivity of detection of the device poor.



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Figure 1c shows the function of the device in the case of an external partial discharge. In this case, there pass through the measuring coil both the current "it" which flows to ground via the transformer winding W and the  
5 current "i" which flows to ground via the capacitive test tap. Thus, the coil measures the current  $i + i_t$ .

The above facts contribute to give the device higher sensitivity to external discharges and hence also to  
10 external disturbances. On the other hand, the sensitivity is low to internal discharges, which is the very phenomenon that is desired to detect. Further, the different sensitivities to internal and external discharges, as well as the sensitivity to internal discharges  
15 which varies with the load impedance, render the calibration of the device difficult.

As mentioned above, it is required that the two measuring channels exhibit the same phase characteristic, which  
20 requires that, for example, the input stage for the signal from the capacitive test tap modifies this measurement signal such that its characteristic as far as possible becomes the same as the signal from the measuring coil. Further, it has proved that an individual adjustment of at  
25 least one input stage is required in connection with installation of the device, which is due, among other things, to variations in cable length and to the type of bushing being used.

30 Figure 2 shows one embodiment of the invention. In this embodiment, the current-carrying return conductor 36 from the signal-processing member SB is not, as in the previously known device, coupled to the ground terminal 34 of the test tap but instead extended past - outside - the  
35 coil 4 to a ground connection 11 on the transformer casing. The conductors 24, 35 and 36 thus form a current coil around the coil for discharge signals originating from inside the transformer, which results in these signals in their entirety being detected by the coil.

The figure shows the case with an internal partial discharge. As is clear from the figure, the coil will detect the whole current  $i + i_z$ . The sensitivity to such discharges will thus be good and its dependence on the load impedance of the transformer is considerably reduced. For an external discharge, on the other hand, only the current  $i_e$  is detected (cf. Fig. 1c). The sensitivity to such discharges, as well as to external disturbances, is thus considerably reduced compared with the known device, which involves an additional advantage.

If the measuring coil 4 were ideal, the current flowing through the conductor 36 would not at all cause any induced voltage in the coil. In practice, there is a risk of this current giving rise to a certain induced voltage in the coil. Under certain circumstances, this may mean that an external discharge or disturbance gives rise to a measurement signal from the coil with such a polarity that the device incorrectly detects the signals as originating from an internal discharge. According to the improvement of the invention shown in Figure 3, there is therefore arranged, in addition to the current path 36 arranged outside the measuring coil, also a second current path 37 traversing the coil. Further, there is arranged a current-distributing member 5, which distributes the current "i" from the test tap between the two current paths. The current distribution is made in such a way that one current  $k \cdot i$  flows through the conductor 37 and one current  $(1-k) \cdot i$  through the conductor 36. The conductors 36 and 37 are connected together after the passage of the conductor 37 through the measuring coil and the current "i" is thereafter passed via a current-measuring device 6 to the ground connection 11. The current-measuring device delivers a measurement signal  $i'$ , corresponding to the current "i", to the signal-processing member SB.

In the case of an internal partial discharge, shown in the figure, the coil measures the current  $i_z + (1-k) \cdot i$

and for an external discharge or disturbance, the following current is measured

$$i_t + k \cdot i$$

It has been found that, with reasonable values of the constant  $k$ , the above-mentioned disadvantage of the device in Figure 2 may be eliminated. Preferably,  $k$  is chosen such that  $0.1 \leq k \leq 0.5$ . A lower value of  $k$  gives higher sensitivity to internal discharges and lower sensitivity to external discharges and disturbances, and is therefore preferable from these points of view. To obtain a simple calibration of the device, however, it may be advantageous to choose  $k = 0.5$ , which - if  $i_z$  and  $i_t$  are small compared with " $i$ " - gives approximately the same sensitivity to internal and external discharges.

Normally, a power transformer has no ground connection which corresponds to the connection 11 in Figures 2 and 3, and in practice it is mostly difficult or unsuitable to arrange such a connection especially for the monitoring device according to the invention. However, a capacitive test tap normally has two connection terminals, one of which is connected to ground. For practical reasons, therefore, it is often desirable to use this ground terminal for ground connection of the monitoring device. Such an embodiment of the device is shown in Figure 4 (also this figure only shows the case of an internal partial discharge). The conductor 36 is there extended upwards through the measuring coil and is coupled to the ground terminal 34 of the test tap via the current measuring device 6. The function is the same as that described with reference to Figure 3, since the current  $(1-k) \cdot i$  flowing upwards through the coil in the figure gives rise to an equal current flowing downwards through the pipe 21 and thus does not cause any net addition to the total current through the measuring coil.

Figure 5 shows how the circuits, connected to the capacitive test tap, are designed in a preferred embodiment of the invention, wherein both the current-distributing

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member 5 and the current-measuring member 6 are constituted by current transformers. The current transformer 5 has two windings 51 and 52. With the chosen winding polarities, a current "i" from the test tap will be distributed between the conductors 36 and 37 with the proportion  $(1-k) \cdot i$  through the conductor 36 and the proportion  $k \cdot i$  through the conductor 37. The ratio between the number of turns of the windings determines the constant k, and, for example in case of equal number of turns of windings,  $k = 0.5$ .

The current transformer 6 has two primary windings, 61 and 62, coupled into the current paths 36 and 37. The secondary winding 63 of the transformer is coupled to the input stage of the signal-processing member SB and delivers thereto a measurement signal  $i'$  corresponding to the sum of the currents in the conductors 36 and 37, that is, to the current "i".

This embodiment has several advantages. The current transformer 6 can be simply designed with the same impedance as the measuring coil. The two measurement signals will then have the same frequency and phase characteristic, which means that the two input circuits in the signal-processing members may be designed identical and that the need of individual adjustment during installation is eliminated. Further, the signal-processing members through the current transformer are galvanically separated from the bushing, which entails a reduced sensitivity to disturbances and overvoltages. An additional advantage is that the capacitive test tap (33) becomes grounded (through the conductors 36, 37 and the current transformers) in a relatively direct and interruption-safe manner, which minimizes the risk of interruptions, which would otherwise damage the bushing.

The embodiments of a device according to the invention described above are only examples, and such a device may

be designed in a large number of other ways within the scope of the invention.

Thus, the invention has been described above in connection to its use in a power transformer. However, a device according to the invention may be used for monitoring partial discharges in other high-voltage equipment or apparatus, for example in gas-insulated switchgear equipment.

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In the examples described above, the invention has been described in connection with a certain type of bushing, but it may, of course, be applied to other types of bushings as well. Also, the measuring coil, which in the examples described is placed between the capacitive test tap and the apparatus (the transformer), may, within the scope of the invention, be alternatively placed on the other side of the test tap (above this in the figures).

20 The embodiments shown in Figures 3 and 4 have current-measuring devices (6), the output signals ( $i'$ ) of which are supplied to the signal-processing members. Alternatively, however, the current "i" of the test tap may also in these embodiments be passed directly to the input stages of the signal-processing members in the manner shown in Figures 1 and 2.

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## CLAIMS

1. A device for monitoring partial discharges in an electric high-voltage apparatus or high-voltage equipment, such as a high-voltage transformer (1), which apparatus has a high-voltage bushing (2) with a capacitive test tap (31-33), and which device comprises an inductive current transducer in the form of a measuring coil (4) arranged around the high-voltage bushing, as well as signal-processing members (SB) adapted, for detection of partial discharges, to be supplied with measurement signals from the inductive current generator (u) and from the capacitive test tap (i, i'), **characterized** in that the device comprises a first current path (36) which is connected to the capacitive test tap and arranged outside the coil and which is arranged so as to form, together with the conductor (24) of the high-voltage bushing, a current loop around the coil for signals coming from inside the apparatus and originating from partial discharges.
2. A device according to claim 1, **characterized** in that it comprises a second current path (37) traversing the coil as well as current-distributing members (5) adapted to distribute a current (i) flowing from the capacitive test tap between the first (36) and second (37) current paths.
3. A device according to claim 2, **characterized** in that the current-distributing member (5) is in the form of a current transformer with a first winding (51) coupled into the first current path (36) and a second winding (52) coupled into the second current path (37).
4. A device according to any of claims 2 and 3, **characterized** in that the current-distributing member (5) is adapted to distribute the current from the capacitive test tap between the current paths such that a current  $(1-k) \cdot i$  passes through the first current path and a current  $k \cdot i$  passes through the second current path, wherein  
i is the current from the capacitive test tap

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k is a constant in the interval  $0.1 \leq k \leq 0.5$ .

5. A device according to any of the preceding claims, **characterized** in that a current transformer (6) is
- 5 arranged for measurement of a current (i) flowing from the capacitive test tap and that the output signal (i') of the current transformer is adapted to be supplied to the signal-processing members (SB).
- 10 6. A device according to claim 5, **characterized** in that the current transformer (6) is designed such that, in relation to the signal-processing members (SB), it exhibits substantially the same impedance as the measuring coil (4).
- 15 7. A device according to any of the preceding claims in an apparatus, the high-voltage bushing of which has a capacitive test tap with two connection terminals (33, 34), one of which (34) constitutes a ground connection,
- 20 **characterized** in that the current path or paths (36, 37) coupled to the capacitive test tap is/are coupled between the two connection terminals (33, 34) of the capacitive test tap.
- 25 8. A device according to any of the preceding claims, **characterized** in that the measuring coil (4) is a Rogowski coil.

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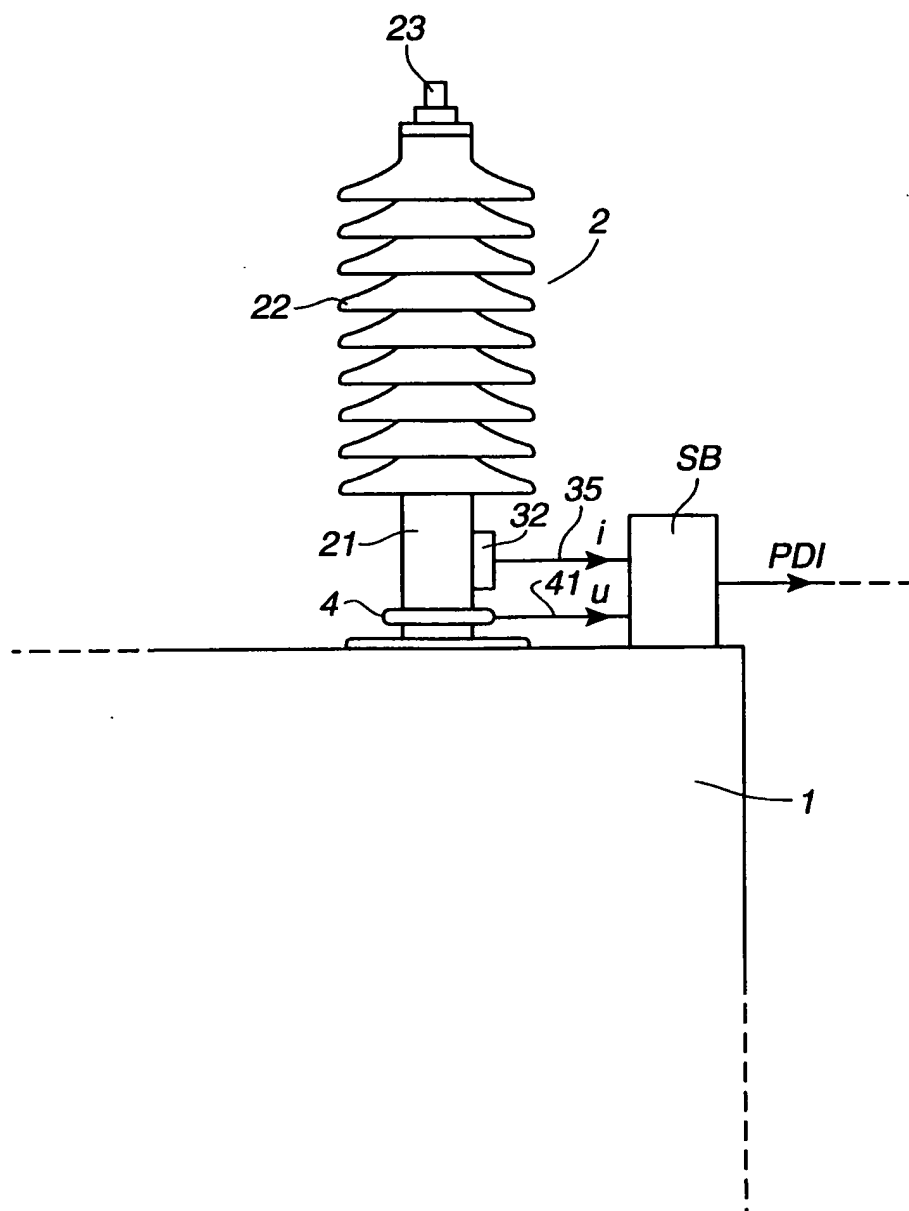


Fig. 1a



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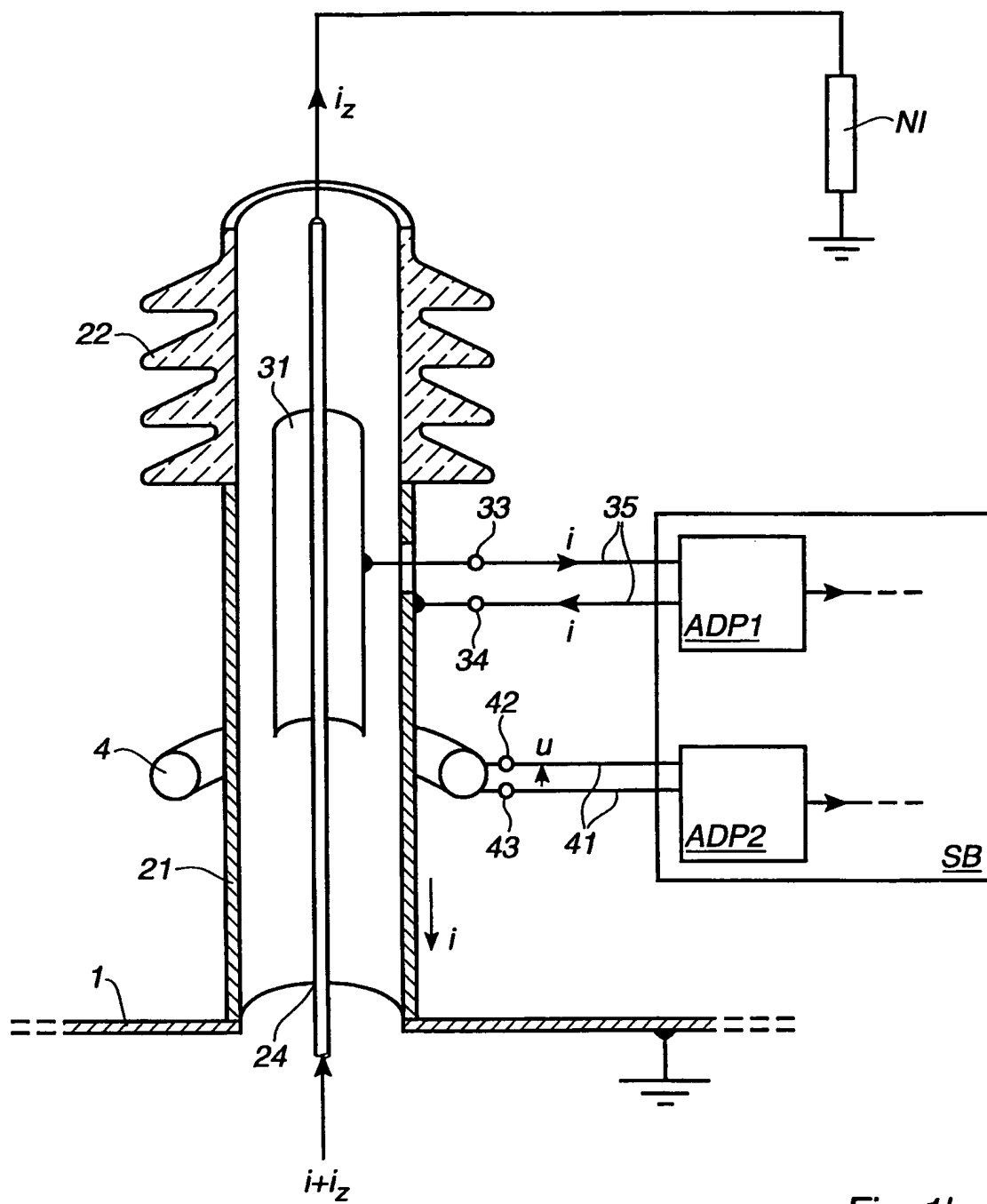


Fig. 1b

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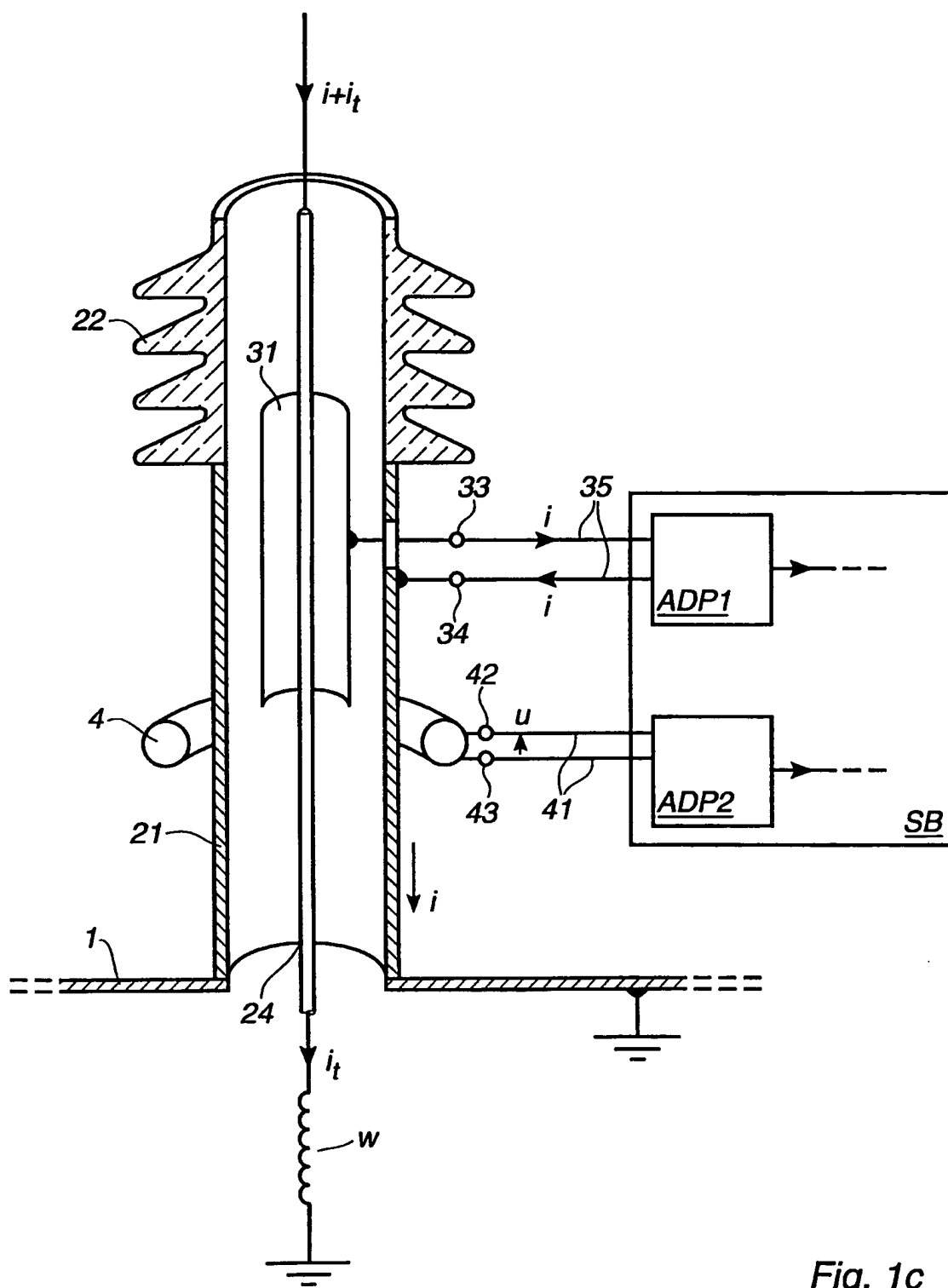
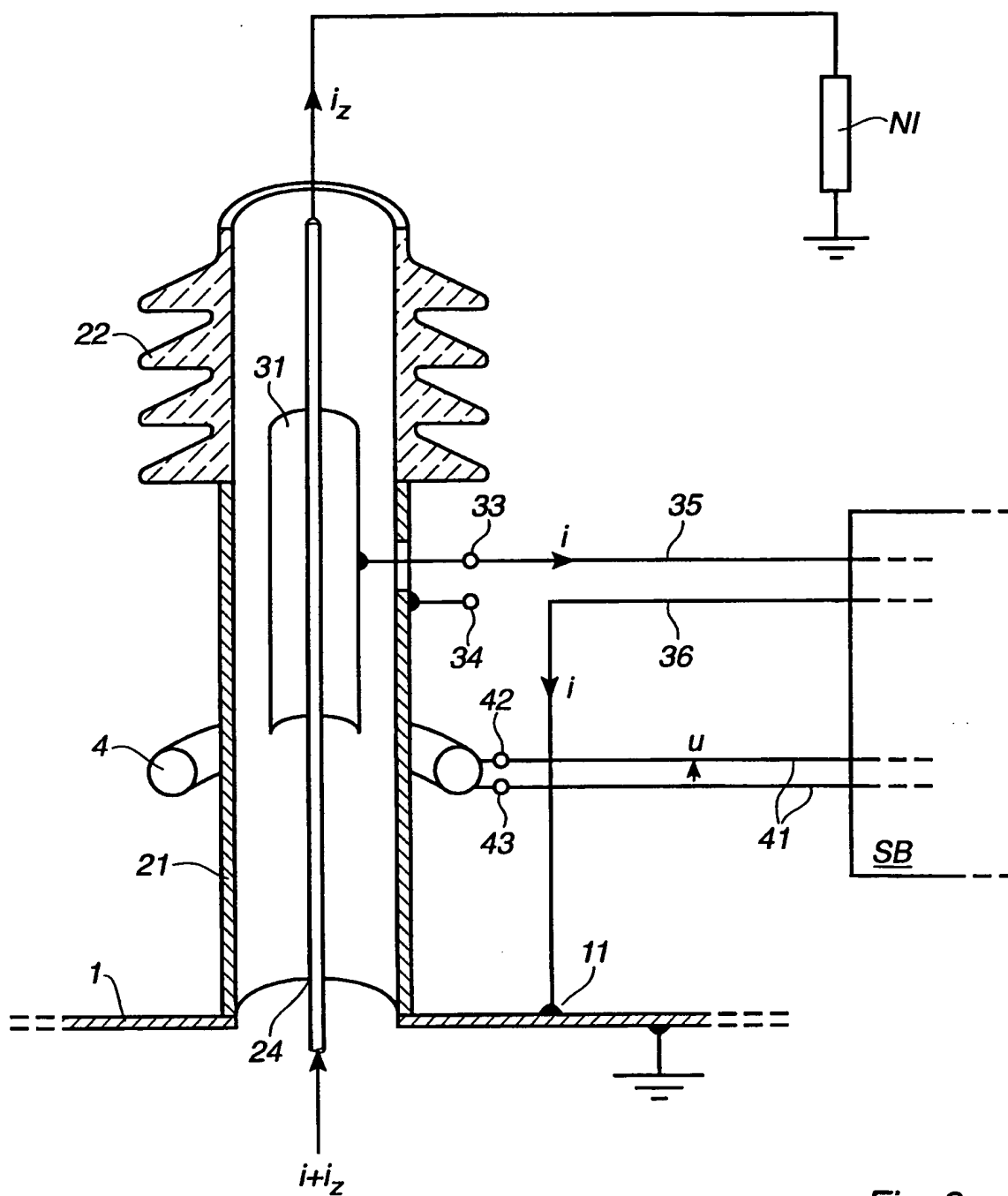
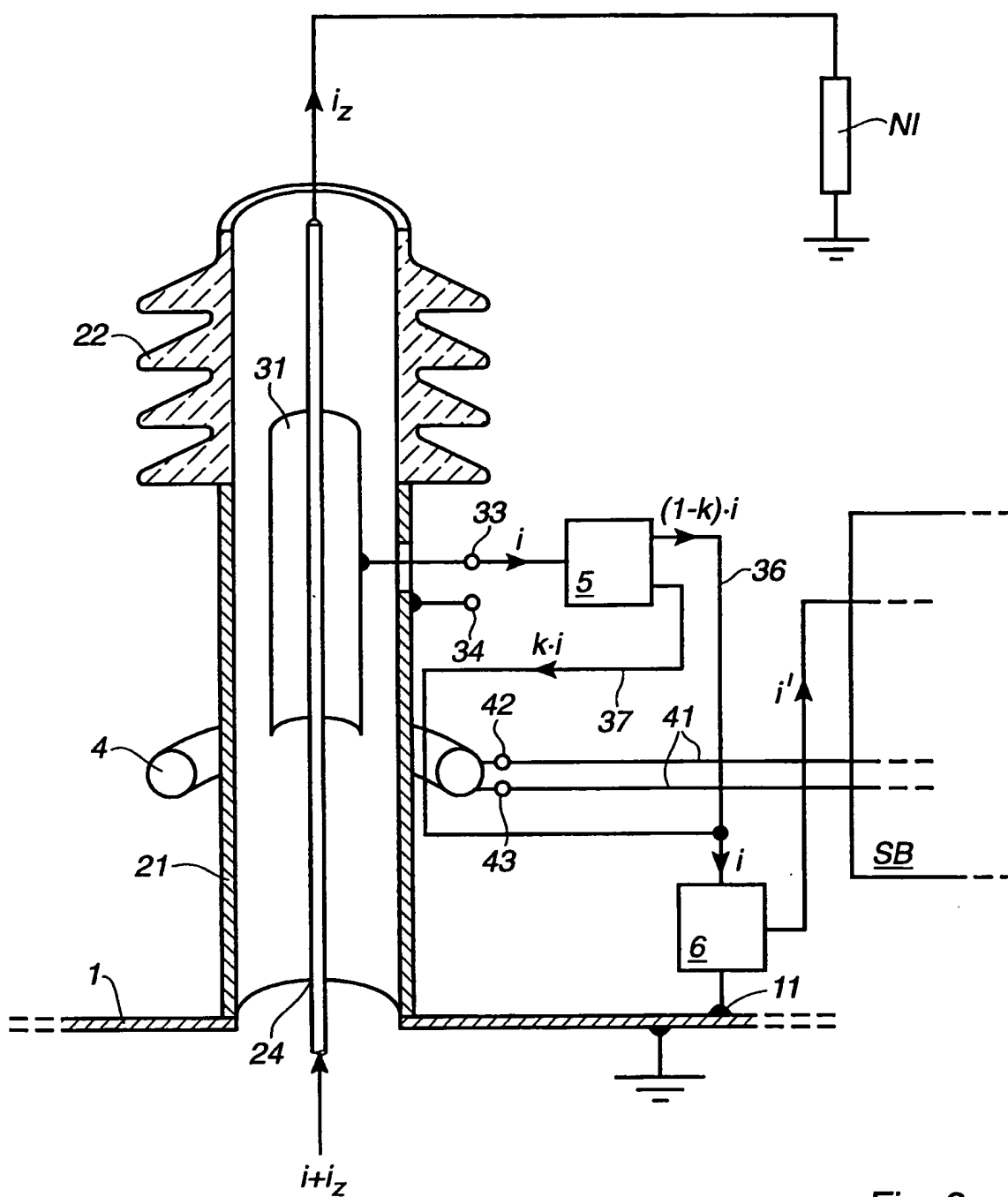


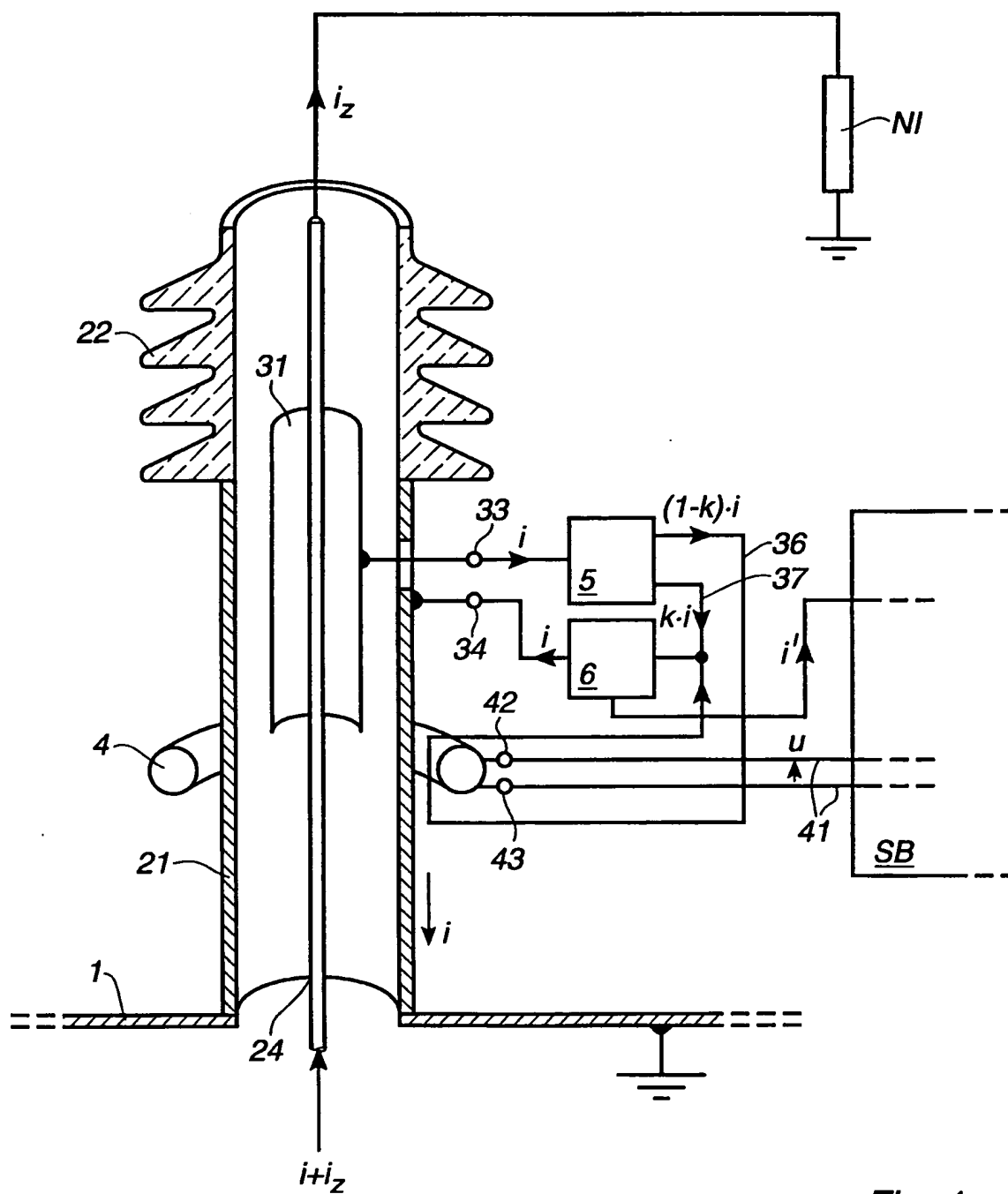
Fig. 1c



**Fig. 2**



**Fig. 3**



**Fig. 4**

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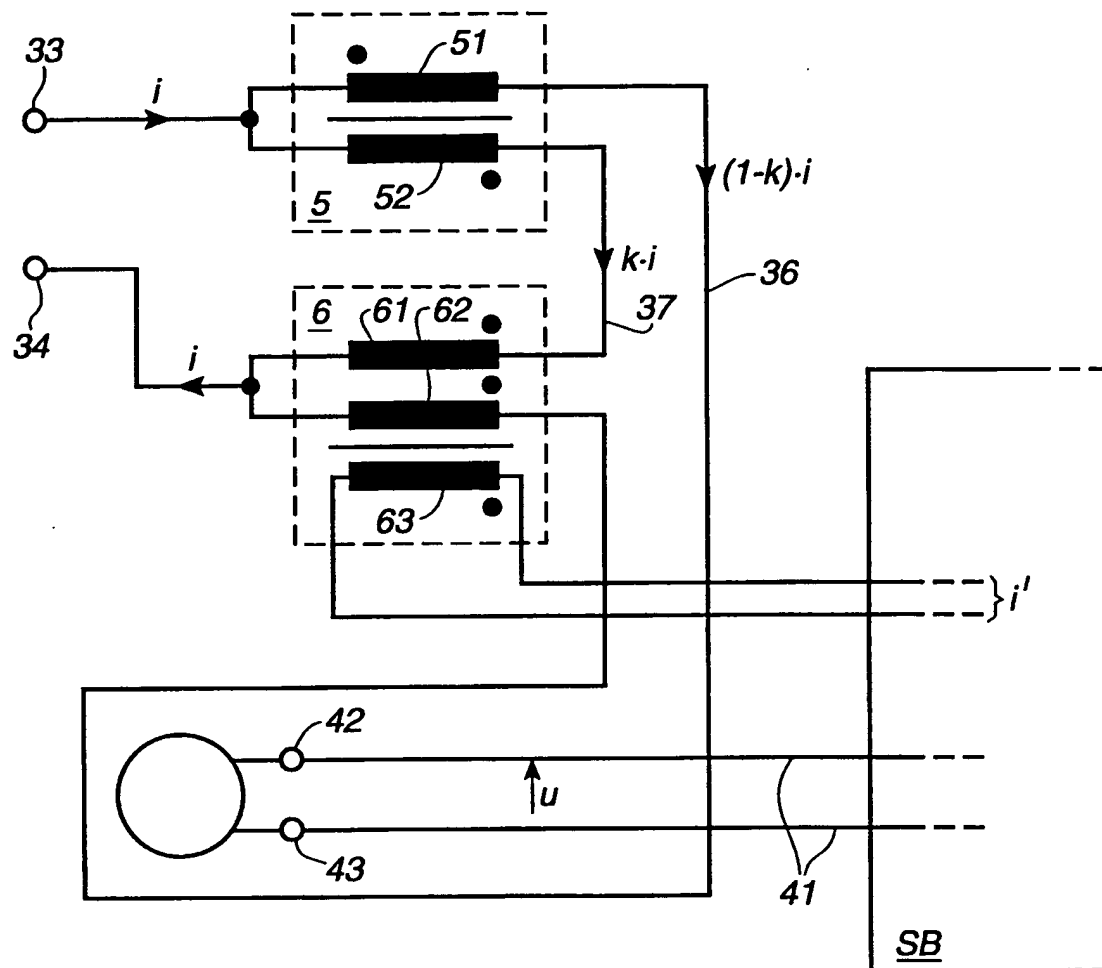


Fig. 5

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/01678

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01R 31/12, H02H 7/04

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G01R, H02H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 3601934 A1 (FELTEN & GUILLEAUME ENERGIETECHNIK GMBH), 30 July 1987 (30.07.87), abstract --	1-8
A	DE 4124268 A1 (FUJI ELECTRIC CO., LTD.), 20 August 1992 (20.08.92), abstract --	1-8
A	US 4897607 A (SIEMENS AKTIENGESELLSCHAFT), 30 January 1990 (30.01.90), abstract --	1-8
E	WO 9635128 A1 (ABB RESEARCH LTD.), 7 November 1996 (07.11.96) -----	

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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